TO WHAT EXTENT DO EARLY LITERACY SKILLS PREDICT GROWTH IN MATHEMATICS FOR STUDENTS WITH READING DIFFICULTIES?

by

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High correlations exist for students who struggle with reading and math, and as a consequence, students who are poor readers tend to do poorly in mathematics. A few studies have investigated the longitudinal growth of the correlation between reading and mathematics. This dissertation outlines the investigation of the relation between reading foundational skills and growth in mathematics achievement for students at risk for reading difficulty and not at risk. This study used extant data from a second grade interim-benchmark reading assessment and a mathematics interim-benchmark for students in third through fifth grade. This study employed a staged approach for the latent growth curve model and discovered estimated differences of students with and without reading difficulties in relation to mathematics achievement. In addition, specific foundational skills were predictive of growth in mathematics for students with and without reading difficulties. The dissertation study developed a theory based on empirical research that early reading skills may lay the foundation for later mathematics achievement.

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For all students who struggle academically, may you too find your journey to be your passion

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CHAPTER I

INTRODUCTION

Accountability testing as a result of No Child Left behind (NCLB) (2002), exerts an enormous influence on the educational system. All students, starting in third grade, must participate in statewide assessments, including students with disabilities (NCLB, 2002). NCLB relies on the statewide assessments of students and student achievement, and these assessments help to ensure adequate yearly progress (Lee & Reeves, 2012). Although NCLB assessments are designed to measure statewide standards in both reading and mathematics and help states identify potentially low, and high-performing schools (Lee & Reeves, 2012), statewide accountability assessments do not, nor can they, account for the tight relationship between reading achievement and mathematics achievement outcomes. In addition, statewide assessments are to include various types of students with disabilities, where this relationship may effect students in a more profound way.

Prior to NCLB, in 2000, the National Institutes of Child Health and Human Development (NICHD) created the National Reading Panel (NRP), in which a group of leading reading specialists and educators discovered a specific formula which defines quality reading instruction. The panel analyzed thousands of studies on reading achievement and instruction that concluded that the five components (i.e., phonemic awareness, phonics, vocabulary, fluency, and comprehension) are essential to good reading instruction (NICHD, 2000). Specifically indicating the importance of these components is included in the instruction of students with reading difficulty. Therefore, four of the five components (i.e., phonemic awareness, phonics, vocabulary, and comprehension) and one additional component, language usage, were analyzed in this study.

The focus for this study is a population of students identified as at-risk for reading difficulties and the influence reading achievement has on mathematics achievement beginning in third grade. Students with reading disabilities or difficulties (RD) are defined as students who are underachieving in reading compared to their peers (Flectcher, Morris, & Lyon, 2003). Currently, forty or more states have adopted the Common Core standards (Common Core, 2011), and they are laying the foundation for statewide assessments. The association between mathematics and reading achievement is not only supported with various studies (Duncan, 2007; Jerman, Reynolds, & Swanson, 2012; Vukovic, 2012; Abedi, 2011), but the relation is found within the standards themselves. For example, the Common Core state standards establish an expectation for kindergartners to grasp propositional phrases and sequencing of vocabulary in reading and mathematics (2011). Much of this relation between reading and mathematics is due to the emphasis on problems applied in everyday contexts As a consequence, many students with disabilities or with reading difficulties are likely to have difficulty accessing the mathematics assessment (Scarpati, Wells, Lewis, & Jirka, 2011).

Nevertheless, for a valid interpretation of mathematics proficiency, the assessment needs to exclude extraneous or unnecessary barriers within the content of items (Messick, 1995; Abedi, Leon, Kao, Bayley, Ewers, Herman, and Mundhenk, 2011). For example, an assessment that includes more complex words or items written in passive voice contributes to the difficulty of the assessment for students at-risk for reading difficulties (Abedi et al., 2011). Complex verbs and subordinate clauses presented in an item are likely to discriminate against students with disabilities.

Because test comprehension requires careful understanding of the construct being assessed, mathematics assessments should not rely on complex verbs and subordinate clauses. Unnecessary language complexity should be eliminated from mathematics assessments because of the difficulty that language complexity presents to students at-risk for reading difficulties (Duncan, 2007; Abedi et al., 2011; Haladyna & Downing, 2004). For this study, third grade initiates the growth trajectory of student's mathematics achievement, because by third grade, educators often contextualize the nature of learning as a transition between learning to read and reading to learn (National Center to Improve the Tools of Educators, 1996). If students are reading to learn by third grade, then focusing on third grade mathematics achievement as predicted by foundational reading skills will show potential barriers to mathematics achievement.

Another source of construct-irrelevant variance embedded in mathematics assessments is vocabulary (Abedi, 2011); however, in some cases, assessing whether a student knows and understands mathematics vocabulary becomes important, such as in the Common Core state standards for third through fifth grade geometry (e.g., axes, coordinates, segments, rays) (2010). Requiring command of subject-specific vocabulary emphasizes the need to give attention to the entire item and whether the purpose of a particular item is vocabulary or a mathematical procedure. Negen & Sarnecka (2012) noted the importance of removing irrelevant language and vocabulary complexities that are not related to the construct being assessed. Otherwise, because language and vocabulary skills are interrelated, mathematics skills such as number learning (Negen & Sarnecka, 2012) utilize both expressive and receptive vocabulary which are likely to influence number-word proficiency.

In summary, the dissertation examines the differences between students with and without reading difficulties on longitudinal mathematics achievement, while considering the predictive validity of foundational literacy skills (i.e., phonological awareness, decoding and phonics, foundational language skills, vocabulary, and comprehension) on growth in mathematics.

Phonological Awareness and Processing

Phonemic awareness is a small unit of speech that corresponds to the letters of an alphabetic system and the understanding that language is composed of small units of sounds (phonemes) (Adams, Foorman, Lundberg, & Beeler, 1998; Moats, 2000; Shaywitz, 2003). Phonological processing refers to the ability to identify, manipulate, produce, and remember speech sounds or phonemes (Moats, 2000). Studies have shown the predictive validity of phonological and phonemic awareness skills to reading achievement (Sarama et al., 2011; Gathercole, Alloway, Willis, and Adams, 2006; Snider; 1995).

In recent studies, phonological awareness and processing are measured in a variety of ways. One way to measure phonological awareness is the Comprehensive Test of Phonological Process (CTOPP), Wise, Pae, Wolfe, Sevcik, Morris, Lovett, &Wolf (2008) used the CTOPP to assess blending. Blending refers to the ability to take given sounds in a particular order and blend them to create a word and an elision. An elision refers to the ability to manipulate sounds to produce a new word (Wise et al., 2008). For example, the student is given the word *powder* orally then asked what word is created if you say powder without the /d/ sound – *power*. In a computer-adaptive assessment phonological and phonemic awareness are measured by incorporating audio with each item. Phonological awareness is measured by, discriminating sounds, such as a baby crying versus a police car, then rhyming all which focus on the larger chunks of sounds. In addition to phonemic awareness which is measured by a students' identifying of specific sounds, manipulating sounds by deletion, or by the addition of sounds.

The connection between phonological awareness and early mathematics was investigated by Wise and colleagues (2008) and Vukovic (2012) for reading and mathematics, specifically phonological awareness and early mathematics (Wise et al., 2008; Vukovic, 2012). While Wise et al (2008) identified phonological awareness skills as a good predictor of mathematical achievement, Vukovic (2012) explained growth in mathematics via phonological processing skills. For example, young students who are not proficient in counting mathematical or alphabetical sequence may have a potential correlation between mathematics and phonological processing skills since both skills require sequencing with oral language (Dehaene, 1997). In previous research, Hanich, Jordan, Kaplan, & Dick (2001) found that reading difficulties and fact retrieval are related by deficits in phonological processing (Bridges & Catts, 2011). Furthermore, Wise et al discovered that phonological awareness skills were the best predictor of math achievement (2008). Other studies on math and reading disability research have begun to investigate which cognitive skills are shared by both constructs. Compton, Fuchs, Fuchs, Lambert, & Hamlett (2011) suggested three possible cognitive domains that could potentially impact comprehension and mathematics: (a) nonverbal problem-solving, (b) concept formation, and (c) processing speed. In line with research done by Vukovic (2012), Fuchs, Compton, Fuchs, Bryant, & Hamlett (2005) found that a stronger predictor of math fact fluency was phonological processing. Fuchs' findings are significant because considering automaticity of phonological processing adds a new lens for creating mathematical assessments.

Research efforts related to phonological processing have studied children from second through fifth grade, whereas Vukovic's (2012) study extends down into kindergarten. To further research phonological processing skills as a predictor of mathematics, this dissertation intends to extend on Vukovic and Wises' theory and inquire about students at-risk for reading difficulties using phonological and phonemic awareness scores to predict growth in mathematics achievement. Vukovic (2012) expresses that the large amount of growth for students in kindergarten and first grade in reading and mathematics can make narrowing what influences a student having difficulty learning challenging. Because of the amount of growth that happens between kindergarten and first grade, this study will focus on in the spring of second grade phonological and phonemic awareness scores.

Decoding and Phonics

Students who are at-risk for RD significantly struggle with decoding: sounding out words (Lyon, 2009; National Reading Panel, 2000; Wolf, 2007). In a seminal article by Perfetti (1985), mastery of phonics was a major source of variation for time students took to read words in isolation. Phonics is defined by Moats (2000), as the relation between letters (the symbol) and the sounds they represent (phoneme), and decoding is the ability to translate words to speech (deciphering a new word by sounding it out) (Moats, 2000). Wise et al (2008) and Vukovic & Siegel (2010) both utilized the decoding and phonics measured by word attack skills, word identification, and letter-word identification from the Woodcock Reading Mastery Test-Revised. Decoding and phonics are measured by letter-sound identification, vowel- spelling patterns, beginning and ending sounds, and long and short vowel combinations.

Significant issues with learning phonemic awareness and phonics lie at the core of many students at-risk for reading difficulties (Moats, 2000; Shaywitz, 2003). The ability to decode is quintessential to comprehension and making meaning from connected text. In theory, if a student struggles to decode, they struggle to comprehend, and the struggles could enviably transfer to achievement in mathematics (Bryant, Nunes, & Barros, 2014). Also attributing to difficulties with mathematics achievement is the inability to decipher words and the amount of time to decode words from print (Wise et al., 2008). A great deal of previous research has explored students at-risk for reading difficulties with word attack measures (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012; Wise et al., 2008; Morin & Franks, 2010; Jerman, Reynolds & Swanson, 2012). However, research such as that conducted by Compton et al. (2012), that focused on reading comprehension, word reading, applied problems, and calculations , was minimal. Compton et al. (2012) examined the cognitive and academic profiles of students with learning disabilities in reading comprehension, word reading, applied problems, and calculations. What Compton et al discovered showed weakness in calculation with word reading in student with disabilities with an effect size of 0.25. One motivation for including phonics in my dissertation is that inclusion provides additional information on this topic about which there is minimal published research.

Vocabulary

Little research has investigated the effect of reading vocabulary on growth in mathematics despite the numerous studies indicating the predictive value of phonemic awareness and decoding on students at-risk for RD (Wise et al., 2007; Catts, Adlof, & Weismer, 2006). Vocabulary can be defined in many ways. For example one definition breaks vocabulary into three large categories: (a) oral language, the ability to produce words and use words appropriately in context (Wise, Sevcik, Morris, Lovett, and Wolf, 2007); (b) receptive vocabulary, the ability to understand the knowledge possessed and not necessarily able to be expressed (Wise et al., 2007); and (c) expressive vocabulary, the ability to express thoughts and knowledge through speaking and/or writing (Lee, 2011). Conversely, Baumann & Graves (2010) defined vocabulary more broadly in categories such as academic vocabulary, domain-specific vocabulary, and general academic vocabulary. Baumann and Graves (2010) define domain-specific academic vocabulary and general academic vocabulary as domains referring to content- specific words such as those relating to biology or civics versus general vocabulary as all-purpose terms appearing across content areas with varying meanings within subjects. The reading measures used for this study are more aligned to the Wise et al (2007) definitions of receptive, expressive, and oral language.

A population of students exists in which reading difficulties do not lie with the inability to decode or with a lack of fluency, but rather the struggle with vocabulary and therefore with reading comprehension (Catts et al., 2006). An example would be student who can read with accuracy and automaticity, but when asked to stop and define a word such as “curve”, was unable to give a definition. Additionally, the student may be unable to answer short comprehension questions or retell the story. Vocabulary should grow in size and complexity over time; deficits in the ability to grow vocabulary and continual restructuring may contribute to reading disabilities (McDowell & Carroll, 2011; Walley et al., 2003). In my dissertation, students who struggle with vocabulary and comprehension but not decoding or fluency may fall into the category of at-risk for reading difficulty.

Negen and Sarnecka (2012) examined the relation between number-word knowledge and general vocabulary by conducting two experiments. The first experiment measured expressive vocabulary with the Woodcock-Johnson test, while the second experiment replicated the first experiment and included receptive vocabulary measured by the Peabody Picture Vocabulary Test. A key finding related to vocabulary and mathematics emerged from this study. Negen and Sarnecka found both expressive and receptive vocabulary are moderately correlated with number-word knowledge. Additionally, Negen and Sarnecka argued that further research should be conducted investigating the link between number concept development and language development. Davidse and colleagues (2014) investigated whether vocabulary explained unique variance in early numeracy because most studies testing co-variation of early literacy and math development had not considered vocabulary. Davidse et al., (2014) used the Peabody Picture Vocabulary Test as an indicator of receptive vocabulary, while addition and subtraction sums within a story context were used for early numeracy skill indicators. The findings suggest that vocabulary also reduced the common variance and correlated with both addition and subtraction sums.

Based on the studies highlighted here, researchers are only beginning to adequately investigate the relation with and influence of vocabulary on mathematics achievement. The findings of the previous research (Davidse et al., 2014; Negen &

Sarnecka., 2012) depict how expressive and receptive vocabulary skills are interrelated and important to predicting various mathematics skills (e.g., number-word knowledge and sums within a story context). These foundational vocabulary skills are correlated to early mathematics, and thus, are potential underpinnings to future difficulties in mathematics achievement.

Foundational Language Skills

The body of literature about the correlations between language usage and mathematics is growing (Davidse et al., 2014; Morin & Franks, 2010; Sarama, Lange, Clements, & Wolfe, 2011). The meaning of language usage is complex depending on the context. For this dissertation study, language was defined as a system with a means of representation and expression (Lahey, 1988; Morin & Franks, 2010), additionally focusing on syntax, sentence structure, and semantics. *Syntax* means words that belong together in an order and grammatical categories to determine a sentence structure, and *semantics* means words in isolation, phrases, and sentences conveying meaning (Moats, 2000). In this study, foundational language skills include the following, both receptive and expressive: (a) grammatical patterns such as identifying whether a sentence spoken orally has correct verb usage, (b) sentence structure, for example, creating a sentence when given the first word, and (c) conventions of language: the ability to identify and apply capitals and punctuation.

Mathematics has a deep, complex language structure that begins with oral language well before students enter kindergarten, examples of which include knowing how many pieces of candy they have in all or whether they are first or second in line at the store (Alt, Arizmendi, & Beal, 2014). Substantial previous research has explored the correlation between oral language usage skills and reading and has found the correlation to be quite large. For example, Catts, Fey, Tomblin, and Zhang (2002) showed that students with language impairments in kindergarten performed worse than their non-language impaired peers in word recognition and reading comprehension. Additionally, 50% of the children with language impairments were considered to have reading disabilities by second and fourth grades (Catts et al., 2002). These results illustrate the importance of language skills and emphasize the potential confounding effects on reading over time.

Alt and colleagues (2014) recognized how heavily dependent mathematics is on language skills. Examining the demand language usage has on mathematics achievement may provide insight on student outcomes for mathematics achievement. For example, a student presented with a math test question such as "Jane has four crayons and Tom has three more than Jane, how many does Tom have?", the student may have a difficult time navigating through the language of the question but understand the concept that seven is three more than four. Struggling to grasp the language structure of math application problems may indicate that poor language skills have a direct effect on mathematics achievement (Alt et al., 2014; Morin & Franks, 2010).

Comprehension

A deficit in reading comprehension is the most critical element for a student at-risk for reading difficulty (Moats, 2000; Wolf, 2007); therefore it is important for the study to investigate predictive validity to mathematical achievement. The definition for reading comprehension continues to evolve because of the number of important components needed to understand text. Weaver (2002) states that reading comprehension begins with decoding and automaticity of words, which melds with syntax, semantics, and overlaps with meta-cognitive skills (e.g., inferring, predicting, compare/contrast, and cause/effect). Berninger and Abott (2010) furthered the definition of comprehension by including physical features such as the ability to see or feel the words. The point Berninger & Abott (2010) make about the definition is important because defining the construct of reading comprehension as including physical attributes will help to define construct-relevant and irrelevant variance to reading comprehension for students with disabilities. Likewise, listening comprehension encompasses many of the same complex skills as reading comprehension. For example, listening comprehension requires the ability to apply language, phonology, syntax, semantics, intonation, inflection, punctuation, structure (stories vs. informational), and combining with all the information being spoken or expressed (Pearson & Fielding, 1982).

Research (Compton et al., 2011; Korhonen, Linnanmaki, and Aunio, 2012) suggests that the relationship between reading comprehension and mathematics achievement is important to understand from an instructional and assessment view but also for students diagnosed with a reading or mathematics disability. Compton et al. (2011) discovered that there is a distinction between students with learning disabilities for reading and learning disabilities for math. They did so by showing the positive relationship between reading and mathematics, such as in students with learning disabilities in applied problems showing relative strength on comprehension and word reading. Conversely, other studies have shown the connection demonstrated by poor comprehension having a potential effect on mathematics achievement. A longitudinal study was conducted by Korhonen et al. to examine the connection between reading comprehension and mathematical performance. Korhonen et al., (2012) found a significant connection between reading comprehension and mathematics achievement and additionally found the reverse to be true: students with low mathematics performance had low scores in reading comprehension. With comprehension as the goal to independent reading, there is a clear need to understand how it potentially overlaps with mathematics achievement.

Theoretical Framework: Task Analyzing Skills Within Mathematics

Many of the studies focused on measuring mathematics achievement or measuring various skills within mathematics with measures such as Key Math assessment or the Woodcock-Johnson and sometimes a mixture of both (Jordan et al., 2002; McClelland, Connor, Jewkes, Cameron, Farris, & Morrison, 2007; Wise et al., 2008; Stanovich & Siegel, 1994). Negen and Sarnecka (2012) focused on number-word knowledge, whereas Jerman et al (2012) used the WRAT-III to assess a broader range of arithmetic skills. For this dissertation, mathematics achievement was measured using multiple-choice items aligned to the common core and NCTM content standards. Specifically, items are aligned to second through fifth grade standards, which include operations and algebraic thinking, number and operations, measurement and data, and geometry.

For this dissertation on the relation of reading and mathematics achievement, one of the goals was to understand the discrepancies in the possible under identification of students with only mathematical difficulties (Fuchs, Fuchs, & Prentice, 2004; Jordan et al., 2003). Wise et al., (2008) found that identifying students with only mathematical deficits was difficult, because classifying a student with mathematics difficulties based on a single measurement in time was problematic due to variances in math achievement over time. Additionally, Swanson, Jerman, and Zheng (2009) questioned whether students with math disabilities can truly be separated from students with reading disabilities where the basics of word attack and short-term memory had high demands on problem-solving. In fact, Swanson et al (2009) found that struggles between students with math difficulties and reading difficulties were moderated by variations of working memory and problem solving in mathematics achievement. Moreover, Duncan et al (2007) similarly emphasize that students who were identified as having a disability in math only also exhibited deficits in reading achievement. In an attempt to demonstrate the strength of the relation between reading and mathematics achievement, Duncan et al (2007) argued that early mathematics achievement was actually a more powerful predictor of later reading achievement than reading achievement predicting later mathematics. Aligning my dissertation with Bulcock & Beebe (1981), found substantial support for their hypothesis that covariation between literacy and numeracy exists. Most of the covariation was attributed to phonics and syntactic-semantic cueing strategies, along with other reading foundational skills. Lastly, Bulcock & Beebe (1981) found that reading and numeration were both equal in their effects on each other.

Summary of the Relation Between Reading and Mathematics

Founded on Bulcock and Beebe (1981) theoretical perspective, many aspects of early literacy foundational skills are correlated to mathematics. The Bulcock and Beebe research laid the groundwork for other previous empirical research on reading skills and mathematics achievement, which put forward various inferences. To begin, early literacy skills appear to largely overlap with mathematics skills, such as vocabulary to number development, phonological processing, and counting. Second, early literacy skills have consistently predicted mathematics achievement within one to two years of growth data. Third, the relationship between a student's mathematic difficulty and a student's difficulty in reading seemed consistent throughout the research, and this in turn creates threats to construct validity. Subsequently, with empirical evidence and justified theory this dissertation study reflects the strong correlation and predictive validity of early literacy skills for students with reading difficulty on mathematics achievement.

Research Questions

The aim of this dissertation is to investigate the relation between early foundational reading skills and growth in mathematics achievement. Specifically, the following research questions will be addressed:

1. Does 3-5th grade mathematics growth differ significantly between students with and without reading difficulties?
2. Are foundational reading skills related to growth in mathematics for students at-risk for reading difficulties?

Using latent growth curve modeling (LGC), the effects of reading foundational skills—phonemic awareness, phonics, vocabulary, language, and comprehension—on student growth in mathematics will be modeled. I hypothesize that students who are at-risk for reading difficulties will display a significantly different growth trajectory in mathematics than their non-reading difficulty peers. Additionally, I postulate that the growth for students at-risk for reading difficulty will have a positive trajectory, and, conversely, the rate of growth will be slower than students not at-risk. I also hypothesize that reading foundational skills are significantly (positively) related to growth in mathematics for students who are at-risk for reading disabilities. The purpose of this dissertation is threefold:

1. This study compares the growth in mathematics achievement of students at-risk for reading difficulties to peers who are not at-risk, while investigating threats to construct validity in assessments (i.e., content, and structural). Thus, within the context of mathematics assessments, this study may provide evidence of construct-irrelevant variance in mathematics assessments caused by deficits in foundational reading skills.

2. This study continues the research conducted by Jordan, Kaplan, and Hanich (2002), who found that reading abilities influence student growth in mathematics. Their research indicated the need to investigate how reading precursors predict later mathematics difficulties. Furthermore, I extend on Vukovic's (2012) research by investigating the ability of second grade phonemic awareness, phonics, language usage, vocabulary and comprehension scores at predicting growth in mathematics.

3. The potential of the predictive utility of foundational reading skills are considered in terms of their relation with mathematics achievement within two structural models; thereby, investigating students at-risk for reading difficulties and typical reader's growth in mathematics. Additionally, my dissertation explores various early literacy skills on mathematics achievement, which is relevant for general and special education teachers. Understanding the relation between early literacy skills and mathematics becomes important information for assessments and the outcomes for students at-risk for reading difficulties. Reading skills are an important factor and are indispensable to understanding the relation with mathematics performance (Rutherford-Becker & Vanderwood, 2009; Jordan et al., 2002; Jordan, Hanich, & Kaplan, 2003).

CHAPTER II

METHODS

Extant data of student mathematics and reading achievement scores were collected during fall 2011 through spring 2014 academic school years from Growth Research Database at Northwest Evaluation Association (NWEA). The Growth Research Database (GRD) is a repository of test even information, which includes test event information, demographics, item information and links to datasets from external agencies such as the National Center for Education Statistic's Common Core of Data (NCES-CCD) (NWEA, 2014).

Sample

For the study, two measures were used: (a) Measures of Academic Progress for Primary Grades (MPG) in reading and (b) Measure of Academic Progress (MAP) in mathematics. The initial data pull was filtered on students who have taken both MPG reading in spring of 2011 and MAP mathematics third through fifth grades in fall of 2011 through spring of 2014. In addition, each student had at least one time point between third and fifth grade mathematics within the data. This preliminary sample totaled 84,780 students from 2,803 districts nationwide in Grades two through five. This group of students was approximately 49% White and 51% males and 49% female (see Table 1). The decision was made to narrow the data sample by removing missing data but maintain enough student cases to allow for a robust the at-risk reading population. Therefore, once the missing data were removed another random sample was pulled narrowing the sample to 5,000 students. The decision for selecting 5,000 students was two-fold. First, it was based on the maintenance of the desired statistical power level of .8, which was done using Soper (2015) a-priori sample size calculator. Second, the sample size needed to ensure a large enough sample for the RD group to maintain power. The ethnic and gender breakdown of the final sample mimicked the breakdown in the original sample of students: approximately 2% Native American or Alaskan, 4% Asian or Pacific Islander, 10% Black or African American, 10% Hispanic, <1% Native Hawaiian or other Pacific Islander, 50% White, 1% Multi-Ethnic, 26% Not Specified or Other, and 51% male and 49% female.

Table 1
Demographic Descriptive Statistics by Sample Size

Characteristic	Total Sample		Analytic Sample	
	N	%	*N*	%
Demographic				
n	84,781		5,000	
Native American or Alaskan	1,674	2.0	81	2.0
Asian or Pacific Islander	3,422	4.0	179	4.0
Black or African American	8,661	10.2	360	7.0
Hispanic	8,113	10.0	482	10.0
Native Hawaiian or other Pacific Islander	151	<1.0	5	<1.0
White or Caucasian	41,614	49.1	2500	50.0
Multi-Ethnic	1,580	2.0	70	2.0
Not Specified or Other	19,565	23.1	1324	26.4
Males	43,514	51.3	2560	51.2
Females	41,266	49.0	2440	49.0
Demographic				
n	84,781		5000	

Measures

Both MPG and MAP are computerized adaptive assessments that schools typically administer at times between their high stakes accountability assessments and are often referred to as interim assessments. Specifically, MAP assessments are typically administered seasonally (fall, winter, and spring) as they were for the students in the study. Both MPG and MAP assessments items are calibrated on a vertical scale that is specific for each subject area, using a one-parameter item response theory model (Rasch) (NWEA, 2011). MAP and MPG assessments show high reliability and consistency attributable to following the AERA/APA/NCME Standards for Educational and Psychological Testing protocol. Specifics around reliability are described later in detail. Because the tests are adaptive, each student experiences a different set of items. Items are selected from a pool of items using an algorithm that searches for the most informative item, where $\hat{\theta}$ is the interim ability estimate and δ is the difficulty of the item required. The test taker's estimated ability is updated after each item response. The update is used to identify the difficulty of the next item to be presented. Because of this method, students have a roughly 50% probability of responding correctly to any given item, with their response (correct/incorrect) driving the selection of the next item presented.

MAP for Primary Grades. The MPG reading assessment is aligned to national reading standards from the International Reading Association (IRA), the National Reading Panel's report, National Council of Teachers of English (NCTE), parts of the book *Preventing Reading Difficulties in Young Children* (National Research Council), and, most recently, Common Core. Foundational skills include phonological awareness, phonics, language, vocabulary, and comprehension. MPG uses the same measurement scale as the MAP assessment, allowing for a direct connection of foundational skills to later student learning (NWEA, 2011). MPG includes several interactive item types, in addition to multiple-choice, in order to reach a board range of early learning skills. For example, a student may be asked to spell a particular word and instead of only choosing the correct answer, she actually spells the word using the letters provided on the screen. The MPG reading foundational skills test includes a large portion of comprehension items with audio read-aloud options. In all subskills, each aspect of the item is reviewed to ensure construct validity. These foundational skills serve as predictor variables, while the outcome latent variable focuses on growth in mathematics achievement.

Measures of Academic Progress 2-5. The MAP 2-5 mathematics assessment is the outcome measure for this study. It is intended for students who have received instruction that is consistent with content standards for grades 2 through 5 as these standards are defined by the Common Core State Standards (CCSS), the National Council of Teachers of Mathematics (NCTM), and various state standards-aligned assessment. The domains within the MAP 2-5 assessment span the grades. Three common domains are represented: (a) operations and algebraic thinking that include problem solving for both addition and subtraction as well as multiplication and division; (b) number and operations in base ten that address place value, counting and cardinality, operations with multi-digit numbers, whole numbers, and operations with decimals; and (c) geometric measurement that includes concepts of area related to multiplication and addition, angles and their measurement, and volume in the context of multiplication and addition (NWEA, 2011).

Reliability. As stated earlier, researchers working on MAP assessments used a method different from the traditional methods for establishing reliability. The classical form of test-retest reliability is not possible because each student is administered a different set of items based their conditional probability of responding to the item correctly (NWEA, 2011). NWEA employs a method suggested by Green, Bock, Humphreys, Linn, and Reckase (1984) termed "stratified, randomly-parallel form reliability" (p.353). Essentially, this is equivalent to alternate-form reliability in which student scores from one test administration are correlated with their scores based on a different, but similar, set of items drawn from the same item pools (NWEA, 2011). The correlations cited for MAP tests are typically separated by several months (e.g., scores from tests administered in the fall correlated with scores from tests administered in the spring). According to NWEA, the equivalent of the test-retest reliability correlations from 2nd grade MPG reading from spring 2008 to spring 2009 ranged from .77 to .82 amongst various states. Similarly, the test-retest correlations of .74 to .80 for 3rd through 5th grade MAP Mathematics assessment, spring 2008 to spring 2009, provide support for the stability of MPG and MAP assessments, regardless of grade or state item pool.

Validity. Validity concerns the extent to which an assessment truly measures what the assessments intend to measure (Joppe, 2000; Golafshani, 2003) and forms the basis for decision-making reflecting the interpretation and uses of the test score (Kane, 2013). NWEA describes validity of MAP as a combination of factors, such as adequacy of test content coverage, the power to yield scores that are predictive of a status, the capacity to draw accurate inferences about a test taker's status with respect to the construct, and the potential to make generalizations from test performance within specific knowledge or performance in similar domains (NWEA, 2011).

Evidence of content validity for MAP and MPG begins with the test and item development process, which is based on procedural evidence. Test structures are created by content specialists, who group state standards into a test design made up of goals and sub-goals. These goals and sub-goals are established by grouping state standards and aligning items in the item bank to those groups. This process has many iterations and includes a validation process by the NWEA Research department. Additionally, items are written to specific standards, which are then reviewed by Content Specialists (NWEA, 2011). Items continue through multiple reviews of item layout, item functioning, and bias and sensitivity. Finally, an item is rendered in the system, reviewed again by the Test Publishing Team for typos or graphical errors, and alternative text for graphics, pictures, and images (NWEA, 2011) is added.

Evidence to support strong validity of MAP assessments comes from the relation of MAP test scores to state content-aligned accountability test scores (NWEA, 2011). The NWEA researchers also investigate three major areas of validity: (a) concurrent validity, (b) predictive validity, and (c) content validity, to ensure validity is adequate for the intended purpose of MAP. Much of NWEA test validity is supported by concurrent relations with other measures. Using state tests aligned with MAP assessments, coefficients in mathematics range from 0.64 to 0.87 for third through fifth graders. In addition to concurrent validity, predictive validity is reported as an additional source of evidence where NWEA assessments are related to performance on other tests measuring achievement in the same domain but at some later point in time (NWEA, 2011). Using state tests with content aligned to MAP tests, correlations range from 0.49 to 0.84 for students in grades two through five.

Analysis and Model Building

Preliminary descriptive analyses were conducted using SPSS 20 (IBM Corp., 2011). Model building was carried out with Mplus 7.1 **(**Muthén & Muthén, 2013**).** Descriptive statistics were calculated for reading and mathematics measures, as well as for student characteristics. Pearson correlations coefficients were used to examine the relation among the variables. In addition, all data were plotted, graphed, and visually inspected to document distributions (normality and variance) and functional form. An a priori decision was made that, due to the large sample size, an alpha value of .01 was necessary.

Latent growth modeling was used to evaluate a set of mathematics growth trajectories spanning grades three through five. With each grade level growth model, model fit was evaluated using predictive fit indices including Akaike's Information Criteria (AIC; smaller values are desirable) and Bayes Information Criteria (BIC; smaller values are desirable) (Kline, 2010), Comparative Fit Index (CFI), .95 or larger indicated acceptable fit, and lastly Root Mean Square Error Absolute (RMSEA), where values less than .08 indicate acceptable fit. Chi-square was considered, but rejected for model fit decisions in view of the large sample size (Cheung & Rensvold, 2002; Kline, 2013; Preacher, Wichman, MacCallum, & Briggs, 2008).

To begin, a growth model was attempted across grades three through fifth, but a complete model fit was not attained. After plotting the means and analyzing the shape of the distribution, it was apparent summer loss between grade levels needed to be accounted for by the model (see Figure 1). Therefore, a piecewise growth model for third grade from fall to spring was fit. A mean intercept and mean slope (with time coded 0, 1, 2, 2, 2, 2, 2, 2, 2), was modeled, starting with third grade and specifying a linear growth model for the first phase of development, for the first three time points **(**Muthén & Muthén, 2013**).** After third grade was determined, fourth grade piecewise model was fit with mean intercept as third grade and mean slope time coded as 0, 0, 0, 0, 1, 2, 2, 2, 2.

An additional summer discontinuity parameter representing potential summer loss between spring third grade and fall fourth grade was added to the third grade growth model represented as 0, 0, 0, 1, 1, 1, 1, 1, 1. The fit of this model was compared to previous models, and it was determined that summer discontinuity parameter should be utilized (see Table 4). Next, fifth grade was added to the model mean with the intercept centered at third grade and time coded for slope of fifth grade coded 0, 0, 0, 0, 0, 0, 0, 1, 2. An additional summer discontinuity parameter representing potential summer loss between spring of fourth grade and fall of fifth grade was added to the model coded between spring of fourth grade and fall of fifth as 0, 0, 0, 0, 0, 0, 1, 1, 1. A comparison of the models indicated that the summer discontinuity parameter should be represented.

Lastly, slope parametrization was determined for mathematics in grades three through five, with a multigroup structural equation modeling used (invariance testing) to compare students at risk for reading difficult (RD) and students without (NRD). Equality constraints were added to the growth parameters to compare model fit and analyze the nested group differences between grades. See Table 1 for model comparisons. Comparing groups within the model is a form of nesting, therefore typically relative fit would be determined by utilizing chi-square goodness of fit test. However due to sample size, the Comparative Fit Index (CFI) was used to compare model fit (Cheung & Rensvold, 2002; Kline, 2014). A model with good CFI equals .95 or larger, to indicate

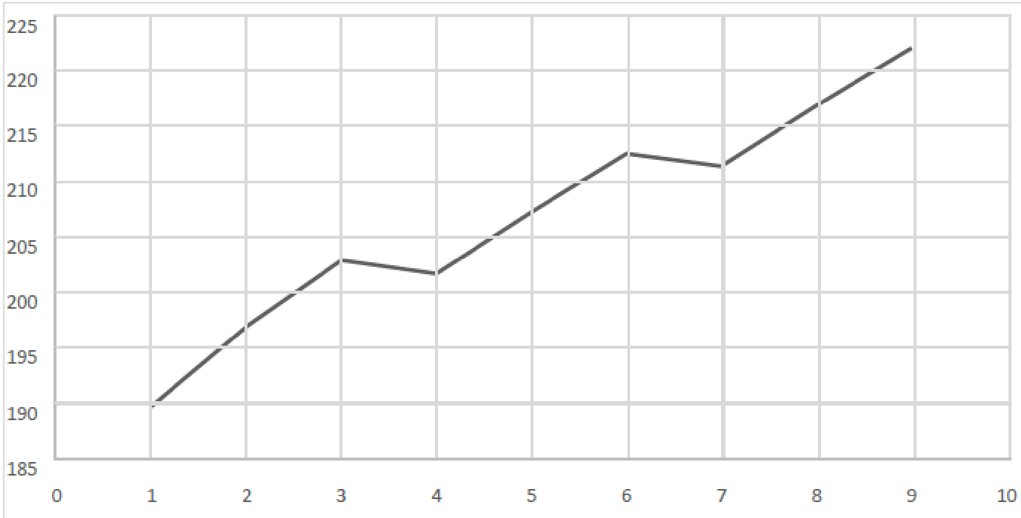

Figure 1. Observed means Grades 3-5th mathematics achievement growth trajectories

acceptable fit, Aikaike's Information Criteria (AIC) and Bayes Information Criteria (BIC) smaller values are wanted, and lastly Root Mean Square Error Absolute (RMSEA) where values less than .08 indicate acceptable fit. The statistical model in Figure 2 shows longitudinal model creating intercepts and slopes for students at-risk for reading difficulty and students not at-risk for reading difficulty mathematics achievement growth.

Once the comparison of the NRD group to the RD mathematics achievement was completed, six reading predictors (e.g., phonemic awareness, phonics, vocabulary, language usage, comprehension, and an overall reading composite score) were added to the model (see Figure 3). Again, fit statistics were compared to the mathematics base model.

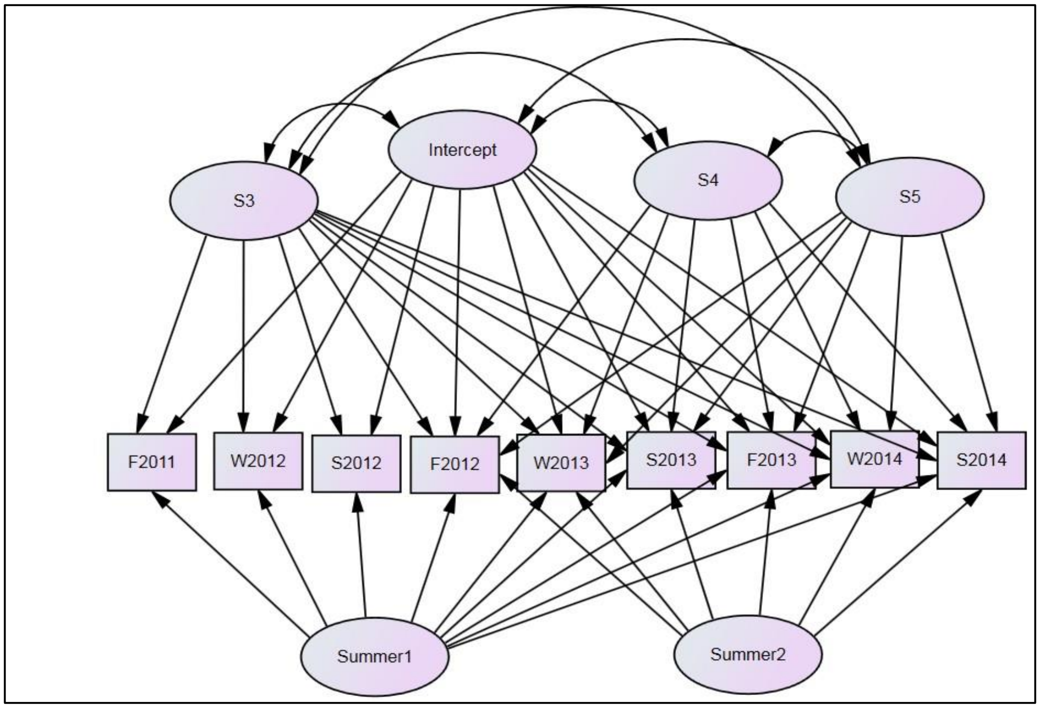

Figure 2. Grades 3-5 mathematics achievement growth and summer discontinuity testing model

CHAPTER III

RESULTS

The preliminary modeling of assumptions indicated that the data in this study were normally distributed without kurtosis or skewness (see Table 2). Additionally, the data were free of outliers. Pearson correlation coefficients were significant between all variables (see Table 3). Finally, means of mathematics achievement performance were plotted and inspected across grades three through five, 3-5 and revealed a positive slope with a significant decline between school years, reflecting the summer loss.

Initially, a growth model for grades three through five mathematic achievements was estimated without the consideration of summer loss. Due to a negative variance for the latent variable, grade five slope variance was fixed at zero, thereby not allowing slopes to estimate freely. The model did not converge, therefore, a second model was generated with the summer discontinuity parameter added and freely estimated. Adding a grouping variable of students not at-risk (NRD) and at-risk for reading difficulty (RD) to the model AIC and BIC values continued to drop from 298112.283 and 298346.90 to 294892.119 and 295361.357. The model with both summer discontinuity and grouping variable of students at risk for reading difficulties (RD) was used throughout the remainder of the study.

Table 2
Descriptive Statistics for Mathematics Achievement by Type of Student

	Student not at-risk (n = 3860)		Student at-risk (n = 1140)		Total (n = 5000)					
Mathematics	*M*	*SD*	*M*	*SD*	*M*	*SD*	*Skewness*	*SE*	*Kurtosis*	*SE*
Grade 3 fall	195.00	10.63	176.30	11.00	190.71	13.26	-.44	.04	.571	.07
Grade 3 winter	201.90	10.10	184.07	11.10	197.80	12.71	-.44	.04	1.07	.07
Grade 3 spring	207.64	10.60	189.60	11.90	203.52	13.25	-.45	.04	.10	.07
Grade 4 fall	206.60	10.74	188.70	11.41	202.50	13.23	-.31	.04	.90	.07
Grade 4 winter	212.20	10.80	194.40	12.00	208.13	13.40	-.40	.04	1.30	.07
Grade 4 spring	218.00	11.70	199.00	12.90	213.63	14.40	-.40	.04	1.20	.07
Grade 5 fall	216.40	12.00	197.60	13.00	212.10	14.53	-.34	.04	1.02	.07
Grade 5 winter	222.00	12.40	202.40	13.31	217.51	15.10	-.30	.04	.64	.07
Grade 5 spring	227.44	14.00	206.30	14.40	223.00	16.50	-.27	.04	.62	.07

Table 3

*Descriptive Statistics and Statistically Significant Correlations for All Study Variables (*n *= 5000)*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	*M* (*SD*)
1. Phonics	--													189 (16)
2. Phonemic Aware	.66**	--												189 (18)
3. Vocabulary	.57**	.57**	--											187 (15)
4. Writing	.58**	.58**	.64**	--										190 (16)
5. Comprehension	.58**	.58**	.67**	.69**	--									190 (16)
6. Fall Math 2011	.57**	.60**	.62**	.67**	.68**	--								191 (13)
7. Winter Math 2012	.58**	.59**	.62**	.65**	.67**	.86**	--							198 (13)
8. Spring Math 2012	.56**	.58**	.60**	.64**	.64**	.82**	.87**	--						204 (13)
9. Fall Math 2012	.56**	.58**	.59**	.64**	.65**	.82**	.85**	.86**	--					203 (13)
10. Winter Math 2013	.56**	.57**	.60**	.64**	.64**	.81**	.84**	.85**	.87**	--				208 (13)
11. Spring Math 2013	.54**	.57**	.59**	.62**	.63**	.80**	.83**	.84**	.86**	.89**	--			214 (14)
12. Fall Math 2013	.54**	.56**	.58**	.63**	.63**	.80**	.83**	.84**	.86**	.87**	.89**	--		212 (15)
13. Winter Math 2014	.54**	.56**	.58**	.63**	.62**	.80**	.83**	.83**	.84**	.86**	.88**	.90**	--	218 (15)
14. Spring Math 2014	.53**	.55**	.57**	.62**	.61**	.78**	.81**	.82**	.83**	.85**	.86**	.88**	.91**	223 (16)

Note. All reported correlations are significant at $p < .05$ or better. *M* = mean, *SD* = standard deviation.
* $p < .01$, ** $p < .001$.

All estimated sample means for the model without the RD and NRD grouping variable were significantly different from zero at $p<.001$. The mean third grade intercept was a RIT value of 190.99 (*SD* = 13.26), the mean third grade slope was 6.38, and the mean of summer discontinuity between third and fourth grade was -1.22. In fourth grade, the mean slope was 5.56 and summer regression between fourth and fifth grade was -2.73. Finally, the mean for fifth grade slope was 5.27. All sample means were statistically significant from zero at $p<.001$.

For students not at-risk for reading difficulties (NRD), the third grade mean intercept was 195.20 (*SD* = 10.63), the mean of third grade slope was 6.31, and the mean of summer discontinuity between third and fourth grade was -1.13. In fourth grade, the mean slope was 5.69, while summer discontinuity was -2.80 and Grade 5 mean slope was 5.54. Results for students at-risk for reading difficulties (RD) had a Grade 3 mean intercept of 176.70 (*SD* = 11.00) and mean slope of 6.61. The mean summer discontinuity between third and fourth grade was -1.08 and the Grade 4 mean slope was 5.14. Summer discontinuity mean in-between fourth and fifth grade was -2.51 and Grade 5 slope mean was 4.38.

Multiple models were run with a constrained model to investigate model invariance longitudinally and compared the RD and NRD groups. Initially, both groups' growth parameters were unconstrained between groups (see Table 4), which was utilized as the comparison group for the constraints. As the unconditional and conditional models are presented the models should be read with the constrained model in mind.

Table 4

Grades 3–5 Mathematics Achievement Growth Model Fit

Model	χ^2	df	AIC	BIC	RMSEA	CFI
1. Without Summer Discontinuity	1488.082	90	67801.802	67998.112	0.176	0.871
2. With Summer Discontinuity	167.622	18	298112.283	298346.90	0.04	0.998
3. Summer Discontinuity + Groups	174.819	36	294892.119	295361.35	0.04	0.997
4. All Grade Mean Constraint	439.738	41	295147.039	295583.69	0.062	0.993
5. All Grade Slope Variance Constraint	505.182	47	295200.482	295598.03	0.062	0.991
6. Residual Variance Constraint	16751.312	65	311410.612	311690.85	0.32	0.687
8. Constraint Model with Reading Predictors	450.50	113	292417.909	292971.87	0.04	0.994

Note. χ^2 = chi-square statistic, RMSEA = Root Mean Square Error Absolute, CFI = Comparative Fit Index.

Unconditional Model

The first step imposed equality constraints on all growth means to determine whether the rate of growth between students not at-risk for reading difficulty (NRD) and at-risk for reading difficulty (RD) students differed, which created Model 4 (see Table 4). According to Cheung and Rensvold (2002), if group sizes are greater than 1,000, then utilizing the change in CFI (ΔCFI) values to be less than or equal to .01 is appropriate (Kline, 2013). The $\Delta CFI = .004$ between NRD and RD, indicating that the constrained invariance hypothesis should not be rejected and therefore growth rate is similar. To investigate variation between group growth trajectories, the slope variance was constrained to be equal for third through fifth graders. (see Table 5, Model 5). The ΔCFI for the slope invariance was less than .01 (see Table 5) indicating the restricted slope invariance hypothesis should not be rejected for the model and the constraint should be retained.

Another hypothesis of equality of residual variances or individual difference parameters (Duncan, Duncan, & Strycker, 2006) was investigated to determine whether the model fit is better for one group over the other (Model 6). When the residual variance was constrained to equal between the NRD and RD groups, model fit significantly worsened. As shown in Table 4, the change in CFI from the previous model was greater than .01 indicating the measurement error between the NRD and RD groups for the latent construct are different (Cheung & Rensvold, 2002). Therefore, the final retained model did not include equality constraint for residual variance.

Table 5
Variance Explained in Endogenous Variables in Grades 3–5 Mathematics Achievement Growth

	Non Reading Difficult (NRD)	Reading Difficulty (RD)	NRD with Reading Predictors	RD with Reading Predictors
Mathematics	--	--	--	--
Fall Grade 3	.81	.70	.78	.70
Winter Grade 3	.82	.77	.82	.75
Spring Grade 3	.85	.82	.81	.76
Fall Grade 4	.85	.79	.83	.79
Winter Grade 4	.84	.79	.84	.79
Spring Grade 4	.90	.85	.86	.81
Fall Grade 5	.88	.86	.86	.85
Winter Grade 5	.88	.85	.88	.85
Spring Grade 5	.90	.84	.86	.83
Latent variables	--	--	--	--
Grade 3-5 intercept	--	--	.45	.34
Grade 3 slope	--	--	.01	.08
Grade 4 slope	--	--	.01	.02
Grade 5 slope	--	--	.01	.01

For the model comparing mathematic growth achievement between NRD and RD groups, all estimated means were statistically significant at p <.001. For the students not at-risk for reading difficulty (NRD) the mean intercept for third through fifth grades was statistically significant (M = 195.83, SD = 10.63) and the mean slope for third through fifth grades was 5.76 (SD = 62.13). Finally the mean summer discontinuity for third through fourth grades was (M = -0.90, SD = 2.54) and for fourth through fifth grades (M = 1.70, SD = 2.13) were both statistically significant (p < .001). The third grade NRD group mean intercept and mean slope displayed statistically significant negative covariance, *cov(i,s)* = -.206, *p* < .001, fourth grade mean intercept and mean slope demonstrate a positive covariance, *cov(i,s)* = .076, *p* < .01. The fifth grade mean intercept and mean slope also displayed a statistically significant, positive covariance, *cov(i,s)* = .196, *p* < .001

In grades three through five, the student at-risk for reading difficulty (RD) group mean intercept and slope were statistically significant at *p* < .001 (*M* = 177.6, *SD* = 9.25), the mean slope was 5.76 (*SD* = 33.76). For summer discontinuity for third through fourth grades mean was -0.74 (*SD* = 4.93) and for grades four through five -2.92 (*SD* = 5.47) both statistically significant at *p* < .001. The third grade RD group mean intercept and mean slope displayed statistically significant positive covariance, *cov(i,s)* = .10, *p* < .001, fourth grade mean intercept and mean slope demonstrated a positive covariance, *cov(i,s)* = .207, *p* < .01. The fifth grade mean intercept and mean slope also displayed a statistically significant, positive covariance, *cov(i,s)* = .08, *p* < .001.

As shown in Table 5 the variance of each observed measure for the unconditional model explained relatively the same amount a variance, even with the reading predictor variables included in the model. The means intercept for the NRD group was statically significant from zero at *p* < .001, (*var* = 44.91). For third through fifth grades, the mean slope was statistically significant variance (*var* = 2.715) and both summer discontinuity means were statistically significant at p < .001 (*var* = 3.50 and *var* = 3.2). The mean intercept for the RD group was also statistically significant from zero at p <.001, (var = 51.22). Because the third through fifth grade mean slopes were constrained to equal variance is the same as the NRD group as indicated above. The means for the discontinuity for the RD group were both statically significant (*var* = 9.72 and *var* = 15.0).

Conditional Model

The initial steps to analyze the conditional model incorporated five reading predictors utilizing a stepwise method. One predictor at a time was added somewhat following the National Reading Panels structure of (PA, PH, VOCB, LG, and COMP) to the unconditional mathematics growth model. Table 6 contains the model fit for each variable incorporated into the conditional model. Path diagrams and results for each iteration of the stepwise conditional model are available in the appendices. The

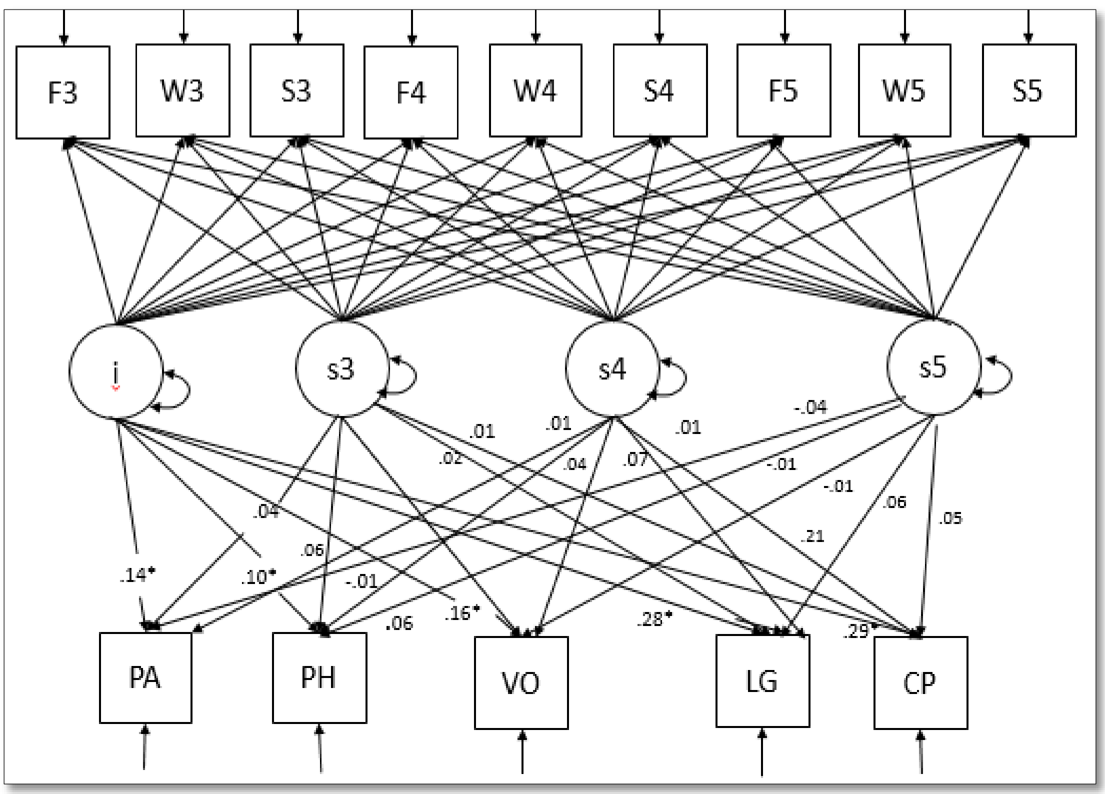

Figure 3. Conditional Model for Students Not At-Risk for RD. Statistically significant (*p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VO: vocabulary, LG: language, CP: comprehension) variables.

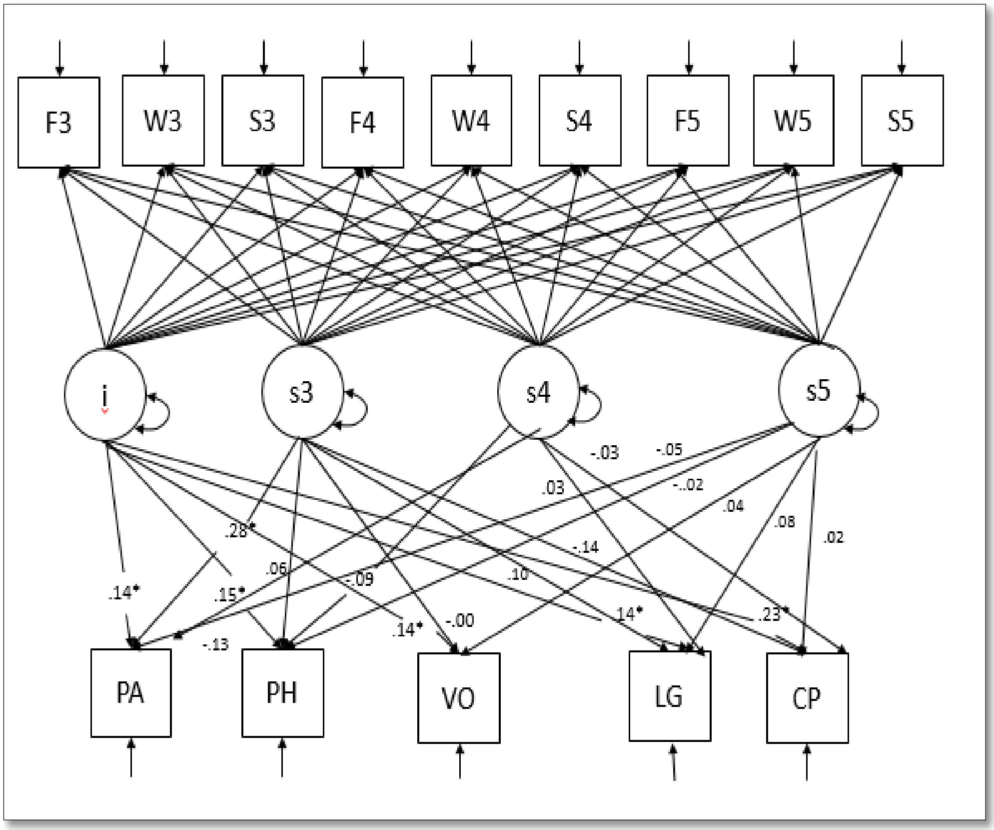

Figure 4. Conditional Model for Students At-Risk for RD. Statistically significant (*p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VO: vocabulary, LG: language, CP: comprehension) variables.

full conditional model results are presented here. See Figure 3 and 4 for a complete path diagram model of both NRD and RD statistically significant (p < .01) pathways.

Not at-risk conditional model. Out of the five reading predictors, all five revealed a mean intercept in grades three through five were statistically significant, p<.01. The reading predictors that were significant were: (a) phonemic awareness (.16), (b) phonics (.10), (c) vocabulary (.16), (d) language usage (.07), and (e) comprehension (.29). The baseline model's predicted rate of growth in grades three through five was constrained to be equal, therefore the NRD and RD groups are expected to demonstrate the same rate in growth. The results of the slope regression paths on each reading predictors at each grade level revealed no significant effect for third and fifth grade. For fourth grade, language usage was significantly different from zero at $p < .01$, (.07). Figure 5 displays the path diagram of the statistically significant relationships between mathematics achievement and foundational reading skills.

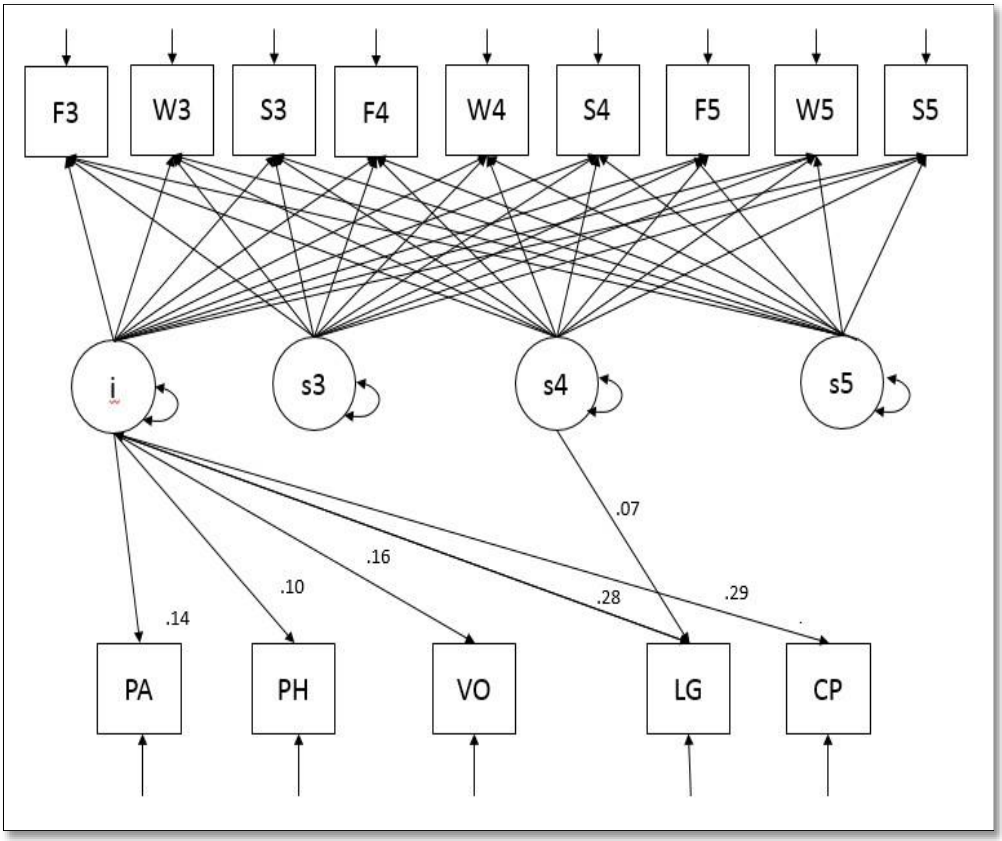

Figure 5. Significant Pathways for Students Not At-Risk for RD. Model Statistically significant (p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VO: vocabulary, LG: language, CP: comprehension,) variables.

At-risk conditional model. Similar to the NRD results, the RD group demonstrated all five reading variables as statistically significant for the intercept: phonemic awareness (14, $p < .01$), phonics (.15, $p < .01$), vocabulary (.14, $p < .01$), language usages (.14, $p < .01$), and comprehension (.23, $p < .01$). In addition, phonemic awareness has a relationship between third grade mathematics and rate in growth, phonemic awareness slope was statistically significant with a positive path of .279, $p < .01$. No additional predictor variables were found significant. Figure 6 displays the statistically significant relationships between mathematics achievement and foundational reading skills.

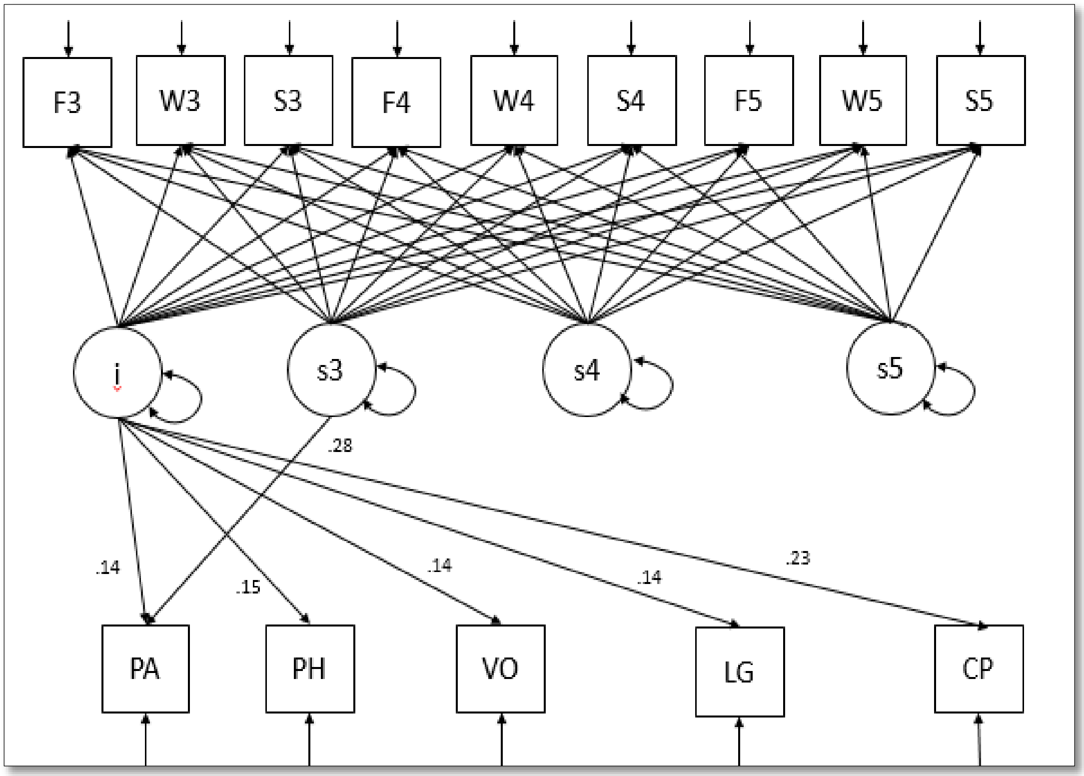

Figure 6. Significant Pathways for Students At-Risk for RD. Statistically significant (p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VO: vocabulary, LG: language, CP: comprehension) variables.

Table 6

Grades 3-5 Conditional Mathematics Achievement Growth with Reading Predictors Model Fit

Model	χ^2	df	AIC	BIC	RMSEA	CFI
1. Math + PA	359.07	73	294250.577	294595.988	.040	.995
2. Math + PA + PH	367.954	83	293982.014	294379.563	.037	.995
3. Math + PA + PH +VO	396.001	93	293431.386	293881.072	.036	.994
4. Math + PA + PH + VO + LG	429.210	103	292800.392	293302.216	.036	.994
5. Math + PA + PH + VO + LG + CP	450.499	113	292417.909	292971.870	.035	.994

Note. χ^2 = chi-square statistic, RMSEA = Root Mean Square Error Absolute, CFI = Comparative Fit Index. Reading variables: Phonemic Awareness (PA), Phonics (PH), Vocabulary (VO), Language Usage (LG), and Comprehension (CP))

CHAPTER IV

DISCUSSION

For students who have strong fluency and comprehension skills, mathematics can be intimidating, but understanding the complexity of mathematics should not be dependent on reading skills. Students with reading difficulties have a dual task of learning the same content as their peers who are proficient readers, while trying to tackle the complexities of reading to decipher mathematics. My dissertation brought to light several findings regarding the differences between students who are at-risk for reading difficulty and those who are not and their growth in mathematics achievement. While most findings were consistent with prior research, others provide original information.

The best fit of grades three through five mathematics achievement growth model stands out as an important finding from my dissertation. The student's initial performance means for grades three through five were different between each group. Even though the students' initial performance was significant, the rate of mathematics achievement growth for students with reading difficulties compared to students without reading difficulties was not significantly different. These findings are unique but consistent with previous research.

Relationships between early reading skills and intermediate mathematics achievement showed that early reading skills are correlated with later mathematics achievement. The various reading skills (i.e., phonological awareness, phonics, vocabulary, language usage, and comprehension) revealed some interesting predictions such as phonemic awareness predicting third grade growth for RD students and language usage predicting fourth grade growth for NRD students and as hypothesized with all five reading covariates predicting initial starting means for RD and NRD students in mathematic achievement. In contrast, only two covariates predicted growth in PA for grade three RD students and Language Usage for grade four NRD students; no other predictions were found to be significant for both groups. Not only were the reading skills strong predictors for the RD group, but for the NRD as well. All reading covariates were strong predictors for the NRD group initial start in mathematics achievement, and language usage was a strong predictor of mathematics achievement for fourth grade.

Unconditional Model of Mathematic Achievement

The first research question established the relationship between students at-risk for reading difficulty (RD) and students not at-risk for reading difficulty (NRD) with mathematics achievement. If mathematics assessments are to be used to measure mathematic achievement, then understanding whether deficits in reading shape student outcomes is important in the relevancy of those assessments. Also, the comparison of RD and NRD students enabled an investigation into whether foundational reading skills could predict where students were performing in mathematics. Consistent with previous research (Jordan, Kaplan, and Hanich, 2002; Duncan, Claessens, Huston, Pagani, Engel, Sexton, Dowsett, Magnuson, Klebanov, Feinstein, Brooks-Gunn, Duckworth, and Japel, 2007), correlation between reading skills and mathematic achievement was significantly positive. A sound link between reading and mathematics is valuable because of the implications these results may have on assessment and instruction.

As with previous research (Libertus, Feigenson,& Halberda, 2011; Saram et al., 2012), differences between NRD and RD students exist between initial performance and growth trajectory. The differences were constants between the two groups for grades three through five and consistent with previous research (Jordan et al., 2003), in which student rate of growth was found not to be different between the NRD and RD groups. In fact, constraining the growth means to be equal proved to be an even better fit.

If RD students' initial performance is far below NRD, but they are growing at the same rate, a number of factors could be contributing to the results. For example, it could be that there is not enough variation in the data or that the instruction some students are receiving is not effective (Firmender, Gavin, & McCoach, 2014). However, the results also could be that strong foundational reading skills, which contain whole to part concepts such as phonemic awareness and phonics, sequential structure like language usage (Wise et al., 2008; Alt et al., 2014), and comprehension of written text lend themselves to more proficiency of mathematic achievement, whereas weaker reading skills act as a barrier to learning strong mathematic skills (Bolt & Thurlow, 2006). Therefore, the RD students are maintaining the same rate in growth, but may never able to "close the gap" with the NRD students.

An important question for this study was whether a difference existed between initial performance means of NRD and RD. The mean for the NRD and RD group were significantly different. The difference was quite large in magnitude and the effect size was substantial indicating that 95% of students performing below the 25% in spring second grade reading MAP test (RD group) are below the mean of the students not at-risk for reading difficulty. Several explanations are possible. First, it may be the skills needed to be strong in mathematics are the same skills for reading (Davidse, Jong, & Bus, 2014). Alternatively, it may be that the mathematics achievement measures do not provide enough access for RD students to remove barriers such as complex language and the ability to decode. Similarly, Rutherford-Becker & Vanderwood (2009) conducted a study investigating the relationship between early reading skills and mathematics and discovered that applied math tests are not solely measuring math skills. An additional finding was that students who performed poorly on reading comprehension were unlikely to be proficient on an applied math assessment. This further emphasizes that it is nearly impossible to disentangle the constructs of mathematics and reading.

Summer loss. Even though the relationship regarding summer loss was not investigated here, the unconditional growth model process in this study confirmed that model fit improved when summer discontinuity was considered, with statistically significant means for both NRD and RD groups. This finding was consistent with studies that include summer loss where students show a drop in growth after the summer break. Since my dissertation was not focused on summer regression an empirical test of whether the summer regressions were equal was not conducted therefore I was unable to determine if the difference was significantly different between the groups.

Relationship Between Reading Skills and Mathematics, Conditional Model

Various research has indicated that the relationship between reading and mathematics is important to understand (Wise et al., 2008; Hart et al., 2010; Davidse et al., 2014; and Sarama et al., 2011) because of the amount of evidence each researcher provides about the overlap between learning reading and mathematics. Wise and colleagues (2008) found that students at-risk for reading and mathematics difficulties that phonemic awareness skills were the best predictor of mathematics achievement. The first step was to establish a relationship by considering the correlations between the reading variables and third through fifth grade mathematics measurements. A moderately high correlation was established between the reading foundational skills and third through fifth grade mathematics achievement (see Table 1), $(r = .53 - .68)$. It is possible that both rely on similar cognitive underpinnings, such as short term memory, pattern finding, and synthesizing information (Hart et al., 2010). Additionally, both reading and mathematics require the ability to comprehend; reading is based on skills that build comprehension, while mathematics, in grades three through five, requires comprehension to analyze problems.

Phonemic awareness. With correlations established and unconditional model found to have good fit, the reading variables were added to the model in a stepwise fashion. For each latent variable, the covariate phonemic awareness (PA) was entered first, followed by phonics (PH), vocabulary (VOC) language usage (LG), and comprehension (CP) (see appendix A for the path diagrams which indicate the result of each step variables).

The results have three primary implications. First, the findings did lend support for previous research that suggest phonological and phonemic awareness are good predictors of mathematical achievement (Wise et al., 2008; Vukovic, 2012). Specifically, results indicate that PA skills were a good predictor of third grade initial performance for mathematics for both NRD and RD students. For every 1.0 unit RIT increase in a PA score, the student initial performance score for mathematics increased by .14 of a Rasch unit.

A number of factors may account for PA predicting mathematics. Compton et al (2011) suggest that cognitive domains potentially share the same skills with PA and therefore serve as common underpinnings of mathematics achievement. It is also noteworthy that, for the RD students, PA was also found to be statistically significant in predicting growth for grade three, as hypothesized (Vukovic, 2012; Wise et al., 2008). For every 1.0 unit RIT a student improves on PA their mathematics achievement score increased by .28. In contrast to Vukovic (2012) and Wise et al (2008), PA was not found to predict growth in mathematics for fourth through fifth grade RD students and third through fifth grade NRD students. These findings may be explained by the amount of variation in mathematics and reading achievement abilities of third graders.

Many third graders are still in various stages of learning to read versus reading to learn, therefore some students may still be considered emergent readers (National Center to Improve the Tools of Educators, 1996). In short, PA predicts mathematics achievement for third grade and is a strong predictor for overall initial mathematics performance.

Decoding and phonics. As expected, the correlations between phonics and mathematics had moderately strong positive relationships. Students that showed stronger phonics ability with higher scores in spring of second grade were expected to (a) predict initial performance achievement for mathematics in third grade, and (b) predict growth trajectory for grades three through five. Results did indicate that for both NRD and RD groups, phonics predicted the initial performance in mathematics achievement. This relationship provides further support of the importance of reading achievement on mathematics achievement and is consistent with Jerman et al. (2012) and Bryant Beebe & Bulcock (1981). Both found poor decoders and poor comprehenders are unable to remove the irrelevant information from math tasks, making such tasks more complex and challenging. Beebe & Bulcock found that phonics had significant contribution to the covariation between literacy and numeracy (1981). These results also emphasize the importance of the strong relationship that foundational reading skills such as phonemic awareness and phonics have with mathematics.

Phonics performance in second grade also predicted third grade initial performance in mathematics. If an NRD student grows 5.0 RIT points in phonics, the student increased .50 RIT points in initial performance in mathematics achievement. For RD students, every 5.0 point RIT gain in phonics equates to .75 initial performance in third grade mathematics achievement. These results suggest that, although proximal, reading achievement in phonics also forecasts mathematics achievement initial performance. This finding is consistent with Bryant, Nunes, & Barros (2014), who found that grapho-phonics mediates the link between student reading ability and success mathematics. In contrast, phonics was not found to be a significant predictor of growth in mathematics performance for grades three through five, for both NRD and RD. However, these results should be reviewed with caution as the reading measure is from an adaptive assessment with only a sampling of items, and therefore may under-represent the construct.

Vocabulary. Similar to PA and phonics, vocabulary had a high correlation with mathematics achievement, ranging from .53 - .62. These results are consistent with Davidse, Jong, and Bus (2014), who report that vocabulary, specifically receptive vocabulary, was correlated with both addition and subtraction sums. Vocabulary is complex and has the potential to contribute to math achievement in a very different way than PA and phonics. For example, a direct overlap exists in curriculum and standards to teach vocabulary in mathematics and in reading. Similar to PA and phonics, vocabulary was also a significant predictor of initial mathematics performance for both third grade NRD and RD groups. Neither group had significant findings for vocabulary achievement predicting growth trajectory for grades three through five. However, further investigation is needed before these results could be generalized.

Language usage. Consistent with current literature, language usage moderately correlated with mathematics (Davidse et al., 2014; Morin & Franks, 2010; Sarama, Lange, Clements, & Wolfe, 2011), with a direct effect on mathematics achievement for students with poor language usage skills (Alt et al., 2014; Morin & Franks, 2010). Language usage was a significant predictor for the RD group's initial performance with a standardized beta weight of .14. With each increase of language usage and writing processing skills, mathematics achievement also increased. Interestingly, for NRD students, the research showed significant increases associated with improvements in language usage and writing process with a standardized beta weight double that of the RD, .28.

A number of factors may explain the NRD group demonstrating a much larger increase in their mathematics achievement with an increase in language skills. For example, students who are able to increase their complexity of language are able to decipher mathematics at a more sophisticated level because of the complex language structure of mathematics. However, it could also be that the similarities between language usage and mathematics is more apparent. The correlations between the language usage variable and mathematics achievement scores were quite strong and large though they also were quite varied, ranging from .62 to .67. These findings may also lend to the argument that the language complexity of mathematical structures can pose as a barrier for some students to show their understanding of mathematics. This theory is consistent with Alt et al (2014), who found large effect size, Cohen's d $(d = 1.97)$, between students with specific language impairments and the Key Math assessment.

Another key finding from language usage was its prediction of mathematics achievement growth trajectory for fourth grade NRD group language usage. The weight was small .07, but still significant at $p < .01$. Whereas for the RD group language usage did not predict any growth trajectories for third through fifth grades. Given that the groups' growth rate was not significantly different, this finding is unique and it may be due to more variation in the NRD group. These findings also suggest that strong language skills may be important for later success in mathematics. It should be noted that nearly 50% of children with language impairments were also considered to have reading disabilities by second and fourth grades (Catts et al., 2002), illustrating the importance of language skills and emphasizing the potential confounding effects on reading over time and thus hindering students' abilities to be fully successful in mathematics.

Comprehension. Similar to the previous findings, the correlations between comprehension and mathematics achievement were quite strong, which is consistent with previous research (Wise et al., 2008; Grimm, 2008). The students who have greater reading comprehension in third grade are more likely to show increases in mathematics skills (Grimm, 2008). In addition to high correlations, comprehension was also another predictor of initial levels of mathematics achievement for grade three for both NRD and RD. However, comprehension was not a predictor of growth trajectories for either the NRD or RD groups at any grade level.

Unlike language usage, comprehension was similar in its relation for both groups of students with NRD at .29 and RD at .23, with NRD weighted slightly higher. Comprehension accounted for the most variance out of all the predictors for foundational reading skills. A deficit in reading comprehension is typical for students at-risk for reading problems, which means its relation to mathematics achievement is critical to consider so that students can access their mathematics assessments.

However, it is essential to understand the various definitions of comprehension. Weaver (2002) states that reading comprehension starts with decoding, fluency of words combined with syntax, semantics and meta-cognitive skills. Berninger and Abott (2010) extend this definition of comprehension to include physical features: the ability to see, feel, or hear the words. As a consequence, reading comprehension becomes quite complex when considering all forms of reading comprehension based on student ability and needs. Furthermore, issues arise in accurately measuring reading comprehension, including biasing results or introducing construct- irrelevant variance. Finally, the relation of the comprehension variable to mathematics may be different for students who need translations, such as English Language Learners or students who need read-aloud to remove decoding barriers. These data, nevertheless, suggest a high correlation between the initial performance reading comprehension and mathematics growth for both RD and NRD groups.

Limitations

Findings from this study must acknowledge several limitations. First, the current study was from a large and nationally representative sample dataset, which offered a great amount of statistical power.

Generalizability. Missing data were removed from the dataset and therefore the ability to generalize the results may be compromised. Additionally, the data in this study measured time in broad seasons: fall, winter, and spring, instead of in a more time sensitive manner such as months or weeks. Measuring time in this manner is slightly less accurate and for future studies a more time sensitive approach is suggested.

Construct validity. Another limitation to consider is MAP for Primary Grades is an adaptive reading assessment with six goal areas, so how the student respond to each item determines the next most informative item for that particular student. This makes the actual sample of items for each goal area dependent on the availability of the breath of the goal area and the depth of item level difficulty, which may under-represent the construct. As for the mathematics achievement construct, it is possible that the MAP mathematics assessment students are taking may be aligned to a variety of mathematics standards from individual states, the Common Core, or NCTM.

Confounding variables. In addition to the potential limited ability of data to fully represent the construct, there are a few other covariates that could have been incorporated into the analyses such as gender and ethnicity. Also, other studies have controlled for intelligence allowing for a deeper level of investigation between students who struggle and the construct being assessed. Lastly, the inability to account for English Language Learners makes it difficult to specify why some students are at-risk for reading difficulty. More specific details about the students could explain more variance, making the results more generalizable.

Despite the effort to create well-represented sample, there are also data collection issues that limit the generalizations to be derived from this study. For this particular study, students at- risk for reading difficulty were decided based on the bottom 25% of the adaptive reading assessment. Even though the reliability of the MPG reading assessment is strong, the construct is broad and not typically used to determine students with reading difficulties. Therefore, this could limit the generalizability of the results and interpretations need to be made with caution. Ideally, several sources would be used to indicate whether the student is consistently struggling with reading to make a stronger argument for risk.

Implications

There are several important conclusions from this study of growth in mathematics for students at-risk or not at-risk for reading difficulties. First, from this large sample of students, it is clear that the relationship between reading and mathematics is strong. Each foundational reading score was able to predict students in both RD and NRD group's initial performance in mathematics achievement, with RD initial performance starting lower than NRD second grade readers. From an assessment standpoint, these differences could help define the construct of mathematics achievement by removing potential barriers such as relying on reading skills to show mathematics understanding.

Latent growth modeling in this study was used to document both initial mathematics scores and average rates of mathematics achievement growth for students who are at-risk and not at-risk for reading difficulty. Students with poor foundational reading skills may begin third grade with low mathematics achievement, but their rate of mathematics growth may accelerate or decelerate (Jordan et al., 2003). In this case, rates of growth for mathematics were the same for students at-risk and not at-risk for reading difficulties (i.e., low initial status with similar growth). Knowing that second grade foundational reading skills may predict initial performance in mathematics has the potential to support teachers so they can adjust their expectations, and be more strategic in their approach around differentiation and instruction. Furthermore, students who are low performing readers with low initial status may need support with reading on mathematics assessments. Removing the barrier of reading to assess mathematics may help to remove bias from a student's test score. Failure to recognize the potential impact poor reading skills may have on mathematics achievement could lead to negative consequences in terms of instruction, assessment and overall growth.

Future studies. To support the ability to generalize this study beyond the current population, a replication study is needed. Are the results similar? Did language usage still predict fourth growth in mathematics for students not at-risk for reading difficulties? Additionally, conducting a correlation study between cognitive skills (e.g., working memory, spatial reasoning, and auditory processing) early literacy skills, and mathematics to find the overlapping skills needed for both reading and mathematics. Understanding this information may help teachers in understanding which strategy to use to support students who are struggling with both reading and mathematics. Lastly, investigating the relation between language usage and mathematics more deeply to potentially uncover more underlying skills that will promote strong mathematics achievement.

APPENDIX

STEPWISE MODELS

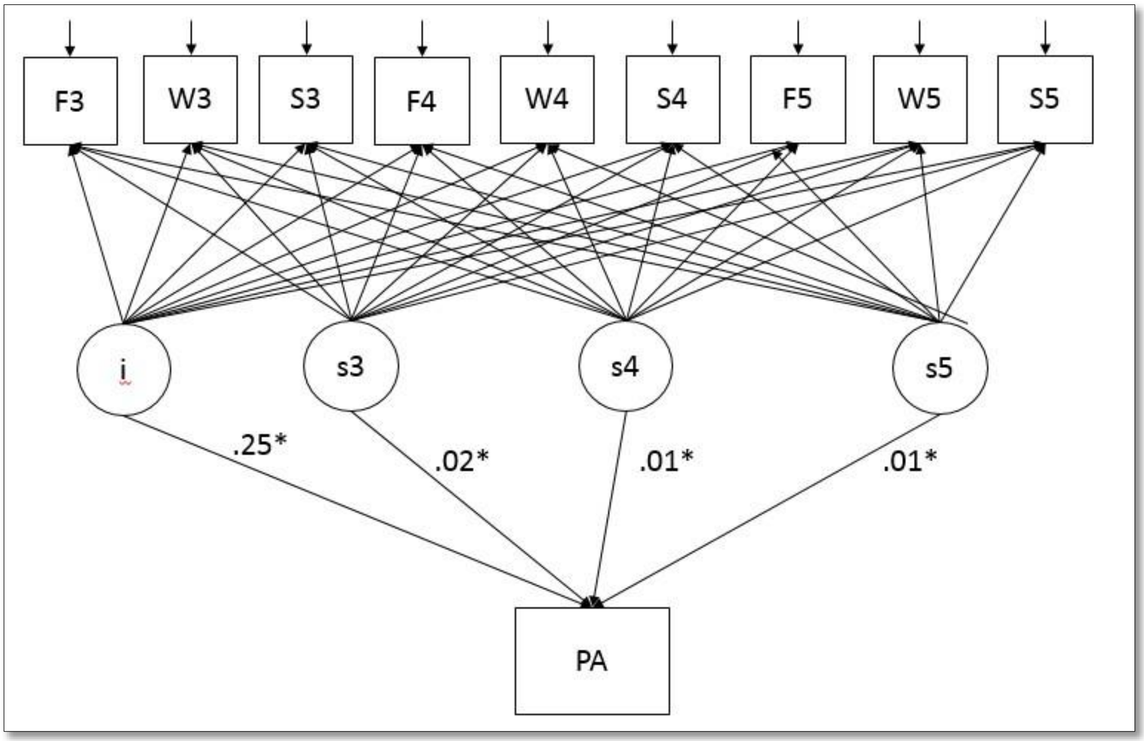

Figure A.1. Conditional Model for Students Not At-Risk for RD, phonemic awareness only. Statistically significant (*p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness) variable.

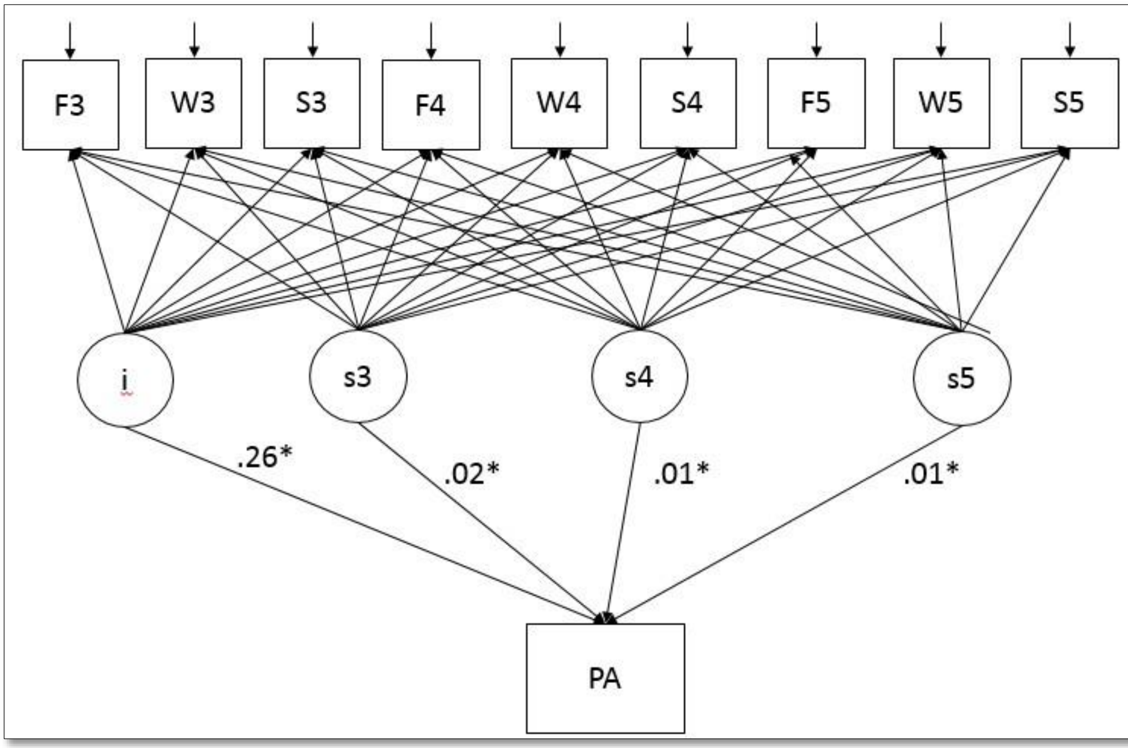

Figure A.2. Conditional Model for Students At-Risk for RD, phonemic awareness only. Statistically significant (*p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness) variable.

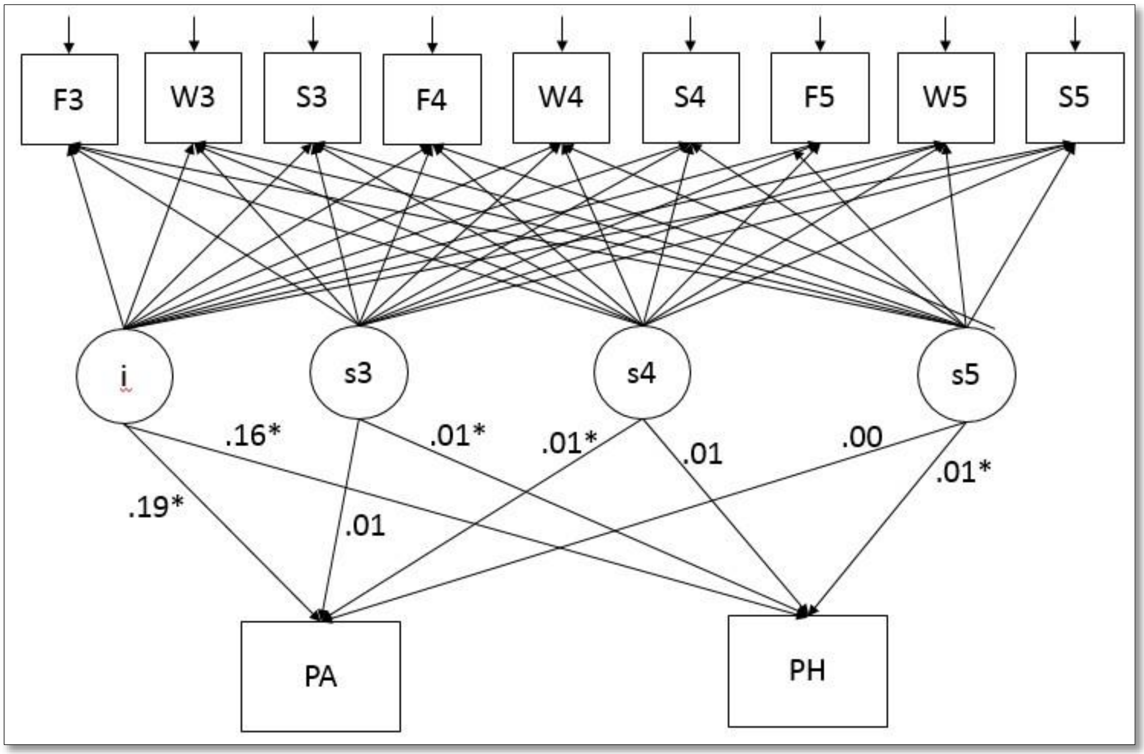

Figure A.3. Conditional Model for Students Not At-Risk for RD. Statistically significant (*p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics) variables.

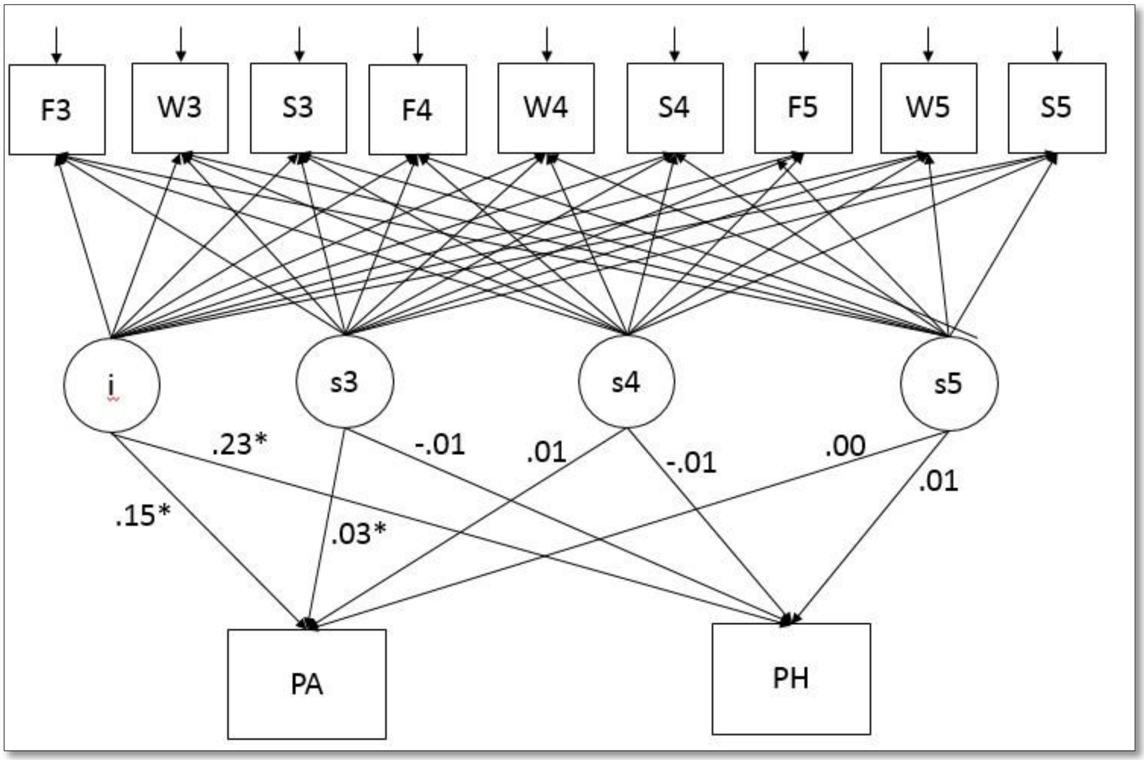

Figure A.4. Conditional Model for Students At-Risk for RD. Statistically significant (*p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics) variables.

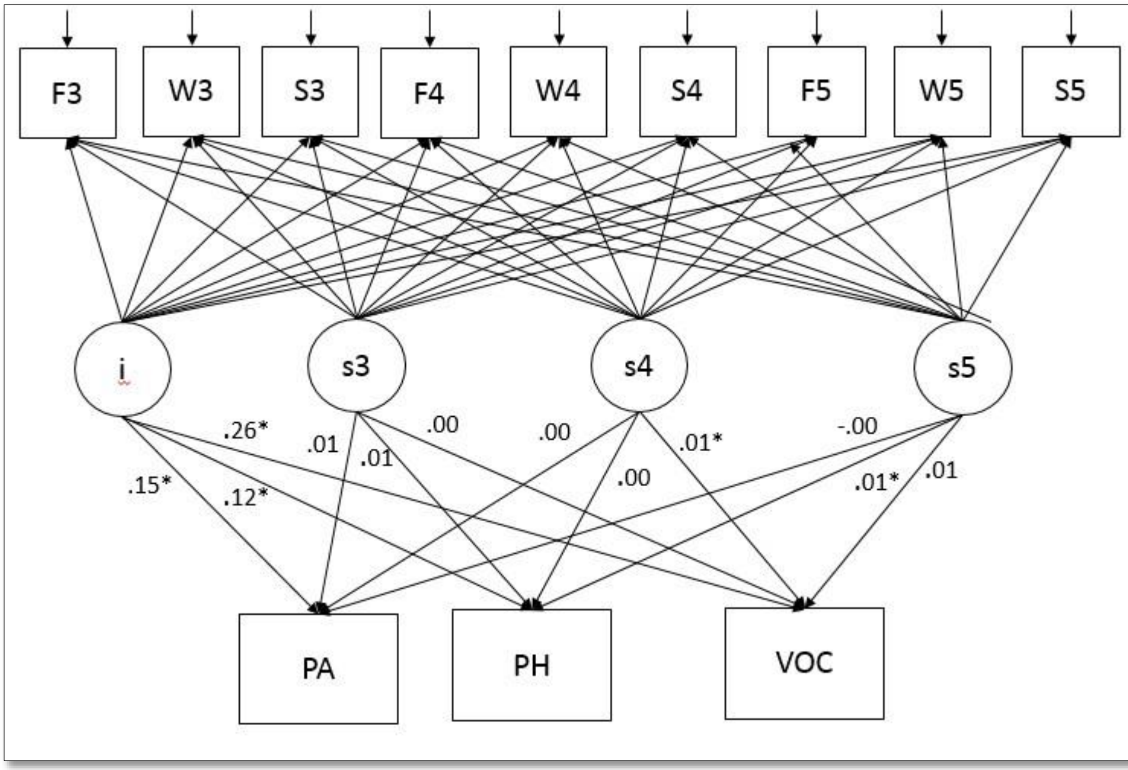

Figure A.5. Conditional Model for Students Not At-Risk for RD. Statistically significant (*p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VOC: vocabulary) variables.

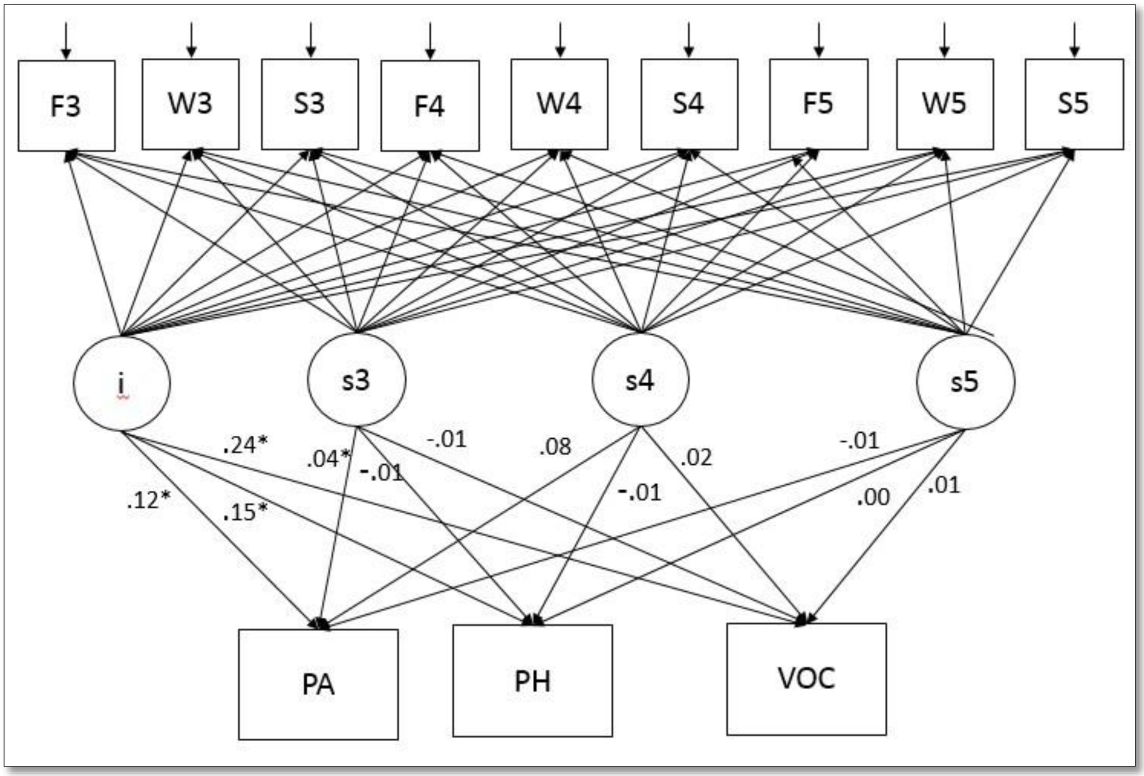

Figure A.6. Conditional Model for Students At-Risk for RD. Statistically significant (*p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VOC: vocabulary) variables.

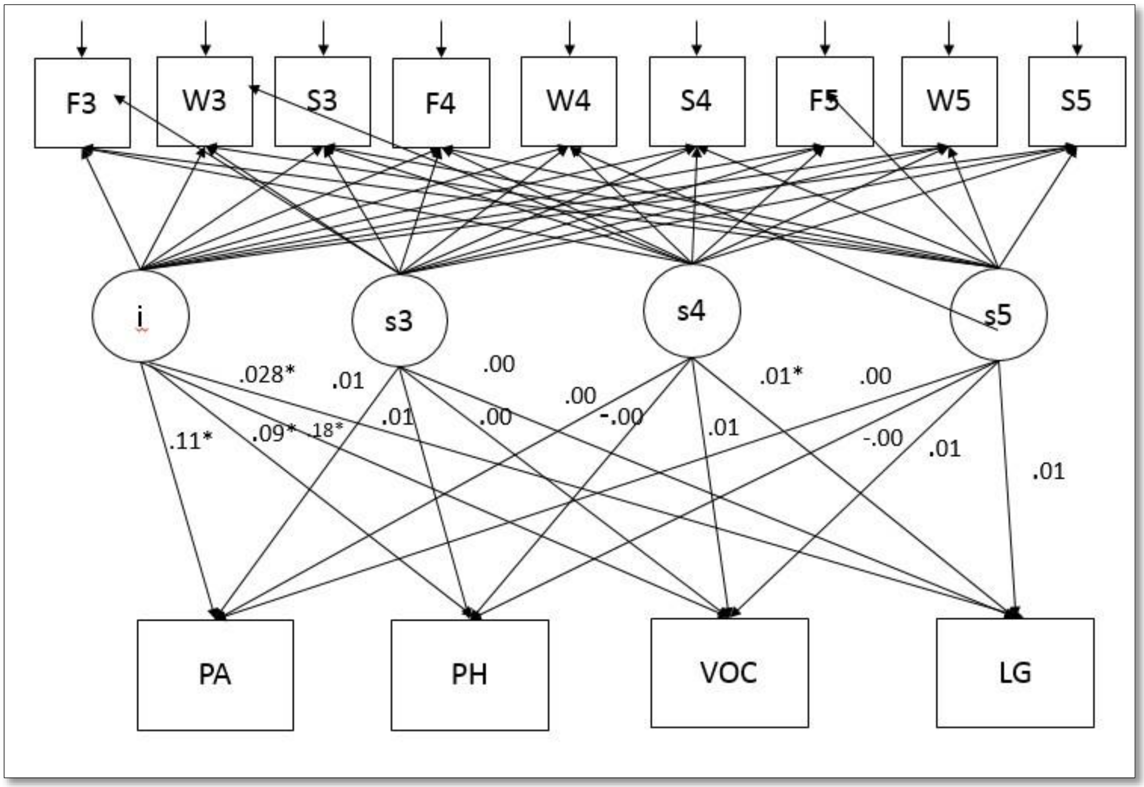

Figure A.7. Conditional Model for Students Not At-Risk for RD. Statistically significant (*p<.01) associations for group NRD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VOC: vocabulary, LG: language usage) variables.

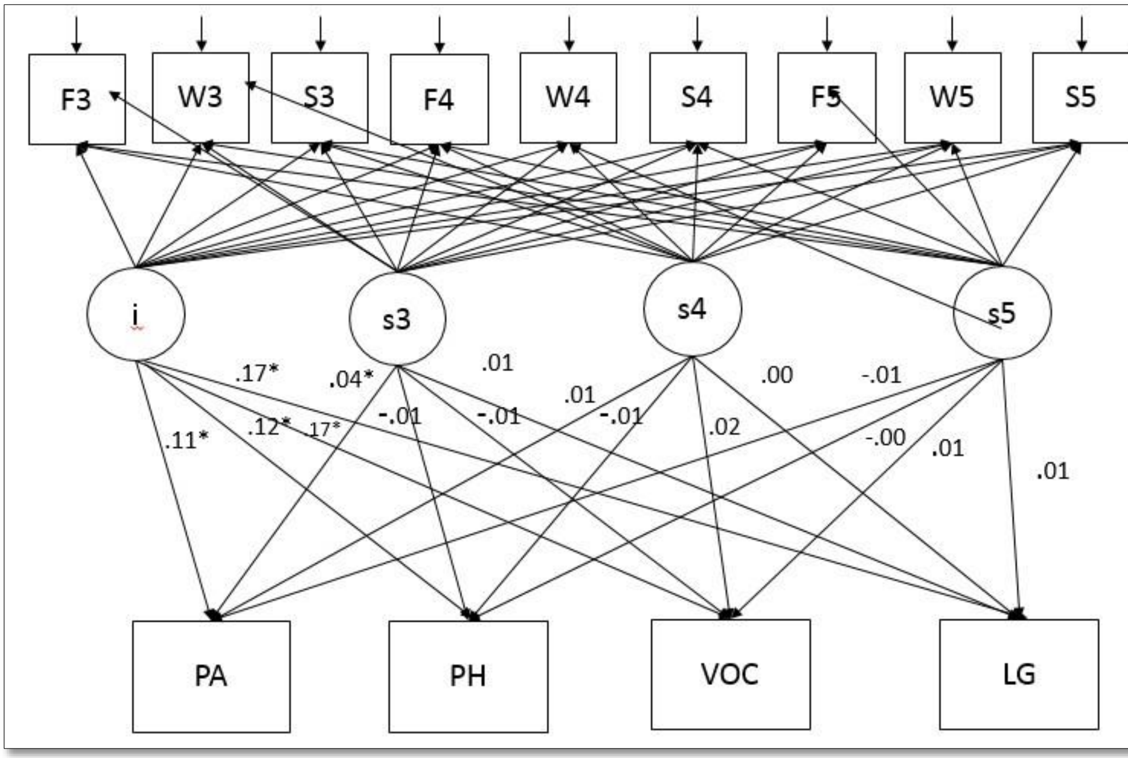

Figure A.8. Conditional Model for Students At-Risk for RD. Statistically significant (*p<.01) associations for group RD Grade 3-5 mathematics achievement and reading predictors (i.e., PA: phonemic awareness, PH: phonics, VOC: vocabulary, LG: language usage) variables.

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